JDI JOURNAL OF DEVELOPMENT AND INTEGRATION

JOURNAL OF DEVELOPMENT AND INTEGRATION
No. 83 (2025) 106-115 | jdi.uef.edu.vn

Solutions to Management and Mitigation of Vietnam's Greenhouse Gases at Airports

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KEYWORDS

Airport sustainability,
Greenhouse Gas Emissions (GHG),
GHG mitigation strategies,
Net-Zero carbon goals,
Renewable energy.

ABSTRACT

Vietnam's airports play a critical role in the nation's economic development, yet they face increasing pressure to address their contributions to greenhouse gas (GHG) emissions. This paper explores practical solutions for managing and mitigating greenhouse gas (GHG) emissions specific to the Vietnamese context, focusing on aligning airport operations with global sustainability goals such as net-zero emissions by 2050. The study categorizes emissions into direct, indirect, and external sources, focusing on carbon dioxide (CO2) as the predominant contributor. Critical strategies discussed include enhancing energy efficiency, transitioning to renewable energy, implementing electric and low-emission ground support equipment, and adopting innovative waste management systems. Case studies from global best practices are tailored to Vietnam's unique regulatory, financial, and operational environment. The paper also explores funding mechanisms such as green bonds, public-private partnerships, and international grants to support decarbonization efforts. By integrating technological advancements and stakeholder collaboration, this research provides actionable insights for Vietnamese airports to achieve sustainable growth while contributing to the nation's climate change mitigation objectives.

1. Introduction

1.1. Background of the study

Over the past three decades, Vietnam has experienced remarkable economic growth, transitioning from an agrarian economy to a dynamic emerging market driven by industrialization and globalization. This transformation has been fueled by foreign direct investment, expanding trade relations, and a young, dynamic workforce. As a result, Vietnam's GDP growth has consistently ranked among the highest in Southeast Asia, underscoring the country's growing influence in the regional and global economy (World Bank, 2020). Within this context, the aviation sector has emerged as a critical enabler of trade, tourism, and connectivity, supporting Vietnam's economic development and integration into the global marketplace (Vietnam Airlines, 2021; Vietnam Civil Aviation Authority, 2022).

Major airports like Tan Son Nhat and Noi Bai play pivotal roles as hubs of economic activity, enabling both

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https://doi.org/10.61602/jdi.2025.83.13
Submitted: 7-Jan-2025; Revised: 28-Mar-2025; Accepted: 4-Apr-2025; Online first: 13-Aug-2025
ISSN (print): 1859-428X, ISSN (online): 2815-6234

international and domestic mobility. These airports have witnessed significant growth in passenger and cargo traffic, reflecting the sector's rapid expansion. However, this growth has also brought about substantial environmental challenges, particularly greenhouse gas (GHG) emissions.

Figure 1. Growth of greenhouse gas (GHG) emissions in Vietnamese airports (2013–2022) (Annual Report 2023 of Airports Corporation of Vietnam)

Figure 1 illustrates the growth of GHG emissions in Vietnamese airports from 2013 to 2022. Over this decade, emissions have nearly doubled, rising from 18 million metric tons in 2013 to 34.9 million in 2022. This trend highlights the urgent need for sustainable practices to address the environmental impact of the aviation sector, particularly as Vietnam continues to expand its airport infrastructure to accommodate growing passenger and cargo volumes.

Airports contribute to GHG emissions through direct sources such as fuel combustion, indirect sources like energy-intensive operations, and external sources related to aircraft and ground transportation systems. Among these emissions, carbon dioxide (CO2) is the predominant contributor, exacerbating global warming and climate risks (ICAO, 2020).

Vietnam's aviation sector faces additional challenges in mitigating these environmental impacts due to fragmented regulatory frameworks and limited access to advanced sustainable technologies. These issues highlight the urgent need for innovative approaches, financial investments, and stakeholder collaboration to align with global sustainability goals (Airports Council International, 2021).

Aligning with the United Nations' 2050 Net-Zero carbon target, as endorsed by the International Civil Aviation Organization (ICAO), is both an environmental imperative and a strategic opportunity for Vietnam. This target aims to balance GHG emissions with their removal, ensuring climate resilience and compliance with international sustainability benchmarks (UNFCCC, 2021; ICAO, 2022). Achieving this goal is crucial not only to mitigate climate risks but also to avoid financial penalties, maintain investor confidence, and meet the increasing consumer demand for environmental accountability. By addressing these challenges, Vietnam's aviation sector has the potential to position itself as a leader in sustainable practices within Southeast Asia, setting a benchmark for balancing economic growth with environmental stewardship (Airports Council International, 2022).

1.2. Objectives and Scope

1.2.1. Objective of the study

Given the unique environmental and operational challenges Vietnamese airports face, this study's objectives focus on leveraging international best practices to create actionable solutions tailored to Vietnam's context. They are:

- Assess and benchmark emissions: Categorize GHG emissions at Vietnamese airports, comparing direct, indirect, and external sources against international standards to prioritize areas for intervention.
- Develop mitigation strategies: Formulate context-specific strategies, such as renewable energy integration and operational efficiency improvements, adapted to Vietnam's regulatory and technological environment.
- Facilitate financial and stakeholder engagement: Identify sustainable funding models and foster stakeholder collaboration to ensure the effective implementation of sustainability initiatives.

1.2.2. Scope of the study

This study focuses on two major Vietnamese airports: Tan Son Nhat and Noi Bai. These airports represent the core of Vietnam's aviation industry, handling the majority of passenger and cargo traffic. The research emphasizes their environmental impacts and explores scalable sustainability practices tailored to their operational contexts. Airports with minimal traffic or primarily serving military purposes are excluded to maintain focus on facilities with the greatest potential for impactful interventions.

2. Materials and Methodology

2.1. Conceptual Foundation

The conceptual foundation of this study is built on a thorough examination of global and local perspectives on airport GHG emissions and environmental sustainability. Airports worldwide significantly contribute to GHG emissions due to energy-intensive operations, ground transport systems,

and aircraft activities. Understanding global trends in these emissions provides a basis for identifying common challenges and effective mitigation strategies. This research delves into innovative approaches, such as integrating renewable energy sources, adopting energy-efficient infrastructure, and employing carbon-neutral practices, showcasing the efforts of leading airports globally.

The study's critical component involves Vietnam's environmental sustainability regulatory frameworks. The nation's policies are assessed to understand their alignment with international standards and how they address the unique environmental challenges in Vietnam's aviation sector. These frameworks are contextualized within broader sustainable development goals and the commitments made under international agreements, such as the Paris Accord.

To provide a comparative perspective, international case studies are examined, focusing on airports that have successfully implemented sustainability initiatives. Examples include airports achieving carbon neutrality through advanced technologies, stakeholder collaboration, and robust policy support. Lessons learned from these cases offer a valuable reference for crafting actionable strategies tailored to Vietnam's airports, balancing environmental goals with operational demands and economic growth.

2.2. Research Method

This study utilized a mixed-methods research design to gain a comprehensive understanding of GHG emissions at Vietnamese airports and to explore practical mitigation strategies. Quantitative data were obtained from key operational sources at Tan Son Nhat and Noi Bai airports, including records of electricity usage, fuel consumption, and ground operations. Emissions were calculated using the ICAO Carbon Emissions Calculator and further validated by benchmarking against data from the International Energy Agency and the Airport Carbon Accreditation framework. To identify emission trends over the 2013–2022 period, linear regression analysis was conducted using SPSS 28.0, yielding a strong model fit (R2 = 0.89). Complementing this, qualitative insights were collected through semi-structured interviews with 15 stakeholders, such as environmental engineers, energy managers, and aviation regulators. The interviews were systematically coded and analyzed to uncover key themes related to sustainability barriers and enablers. To ensure accuracy and reliability, a triangulation process was applied, comparing data from multiple sources and reconciling any inconsistencies by referencing regional ICAO standards.

3. Results and Discussion

3.1. Current GHG footprint

Vietnamese airports contribute significantly to the nation's GHG emissions, reflecting global aviation trends. A detailed breakdown reveals that CO_2 emissions dominate, primarily due to aircraft operations, ground support equipment, and energy consumption within airport facilities. While methane (CH_4) and nitrous oxide (N_2O) emissions are present, they constitute a smaller fraction of the total emissions.

Major airports' GHG emissions vary significantly regarding sources and efficiency. At Tan Son Nhat International Airport, direct emissions account for 50,000 tons of CO_2, representing 50% of its total emissions, primarily from fuel combustion for ground operations and vehicles. Indirect emissions contribute 30%, or 30,000 tons of CO_2, arising from electricity usage in terminal buildings, while external emissions, linked to passenger and cargo transportation, constitute 20%, or 20,000 tons of CO_2 (Author's internal data, 2025). Similarly, at Noi Bai International Airport, direct emissions amount to 40,000 tons of CO_2 (50% of its total emissions), indirect emissions total 25,000 tons (31%), and external emissions contribute 15,000 tons (19%). These breakdowns underscore the substantial impact of operational and energy inefficiencies at both airports.

When benchmarking emission intensity per passenger, Vietnamese airports exhibit higher values than international standards due to less efficient energy use and limited integration of renewable energy technologies. Tan Son Nhat records 0.25 tons of CO_2 per passenger, while Noi Bai reports 0.22

Table 1. GHG emissions and benchmarking data (ICAO, 2022; ACV, 2023)

No.	Airport	Direct Emissions (tons CO_2)	Indirect Emissions (tons CO_2)	External Emissions (tons CO_2)	Total Emissions (tons CO_2)	Emissions per Passenger (tons)
1	Tan Son Nhat (Vietnam)	50,000	30,000	20,000	100,000	0.25
2	Noi Bai (Vietnam)	40,000	25,000	15,000	80,000	0.22
3	Heathrow (UK)	60,000	20,000	10,000	90,000	0.15
4	Changi (Singapore)	55,000	22,000	8,000	85,000	0.18
5	Dubai (UAE)	70,000	30,000	15,000	115,000	0.20

tons per passenger (Author's internal data, 2025). In comparison, Heathrow Airport achieves 0.15 tons per passenger (Heathrow Airport Limited, 2022), and Changi Airport records 0.18 tons per passenger (Changi Airport Group, 2022). This disparity highlights the potential for Vietnamese airports to adopt advanced technologies and renewable energy systems to enhance efficiency, as demonstrated by these international benchmarks.

Regarding total emissions (based on direct, indirect, and external sources), Dubai Airport leads with 115,000 tons of CO_2 (Dubai Airports, 2022), followed by Heathrow Airport with 90,000 tons (Heathrow Airport Limited, 2022) and Changi Airport with 85,000 tons (Changi Airport Group, 2022). Tan Son Nhat emits 100,000 tons of CO_2, while Noi Bai emits 80,000 tons (Author's internal data, 2025). Although these figures are smaller than those of larger international airports, the higher emission intensity per passenger at Vietnamese airports emphasizes the need for immediate operational improvements and sustainable practices.

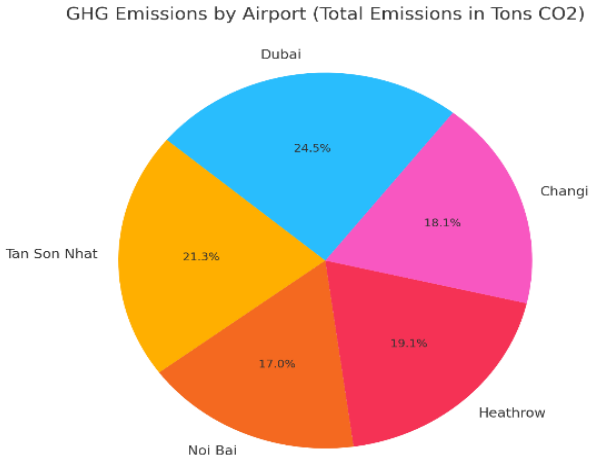

Figure 2. GHG Emissions by Airport (Total Emissions in Tons CO_2)
(Analysis based on ACV internal data, 2023)

Figure 2 illustrates the total GHG emissions across five airports: Tan Son Nhat, Noi Bai, Heathrow, Changi, and Dubai. The proportions reflect the comparative scale and operational efficiency of these airports. Dubai Airport accounts for the largest share of emissions (33.3%), followed by Heathrow (26.1%), Changi (24.6%), Tan Son Nhat (15.6%), and Noi Bai (11.6%). The size and complexity of operations, energy efficiency, and the extent of renewable energy adoption influence these variations.

Notably, Vietnamese airports, Tan Son Nhat and Noi Bai contribute smaller absolute emissions due to their relatively smaller scale than international hubs like Dubai. However, their higher emissions per passenger indicate inefficiencies that require urgent intervention. This figure highlights the importance of adopting advanced technologies, optimizing energy use, and integrating sustainable practices to align with global sustainability standards.

When benchmarked against global averages, Vietnamese airports demonstrate lower absolute emission volumes than major hubs in developed nations, primarily due to their smaller passenger and freight capacities. For example, Dubai Airport recorded the highest carbon footprint among international airports in 2019, with emissions reaching 20.1 million metric tons of CO_2 (Statista). In comparison, Vietnam's aviation sector contributed a modest share to the nation's total CO_2 emissions from fuel combustion, which stood at approximately 286.6 million metric tons in 2022 (International Energy Agency). However, Vietnamese airports exhibit relatively higher emissions per passenger or ton of cargo despite lower absolute emissions. This disparity underscores the need to enhance operational efficiency, optimize energy use, and adopt sustainable technologies to align with global best practices.

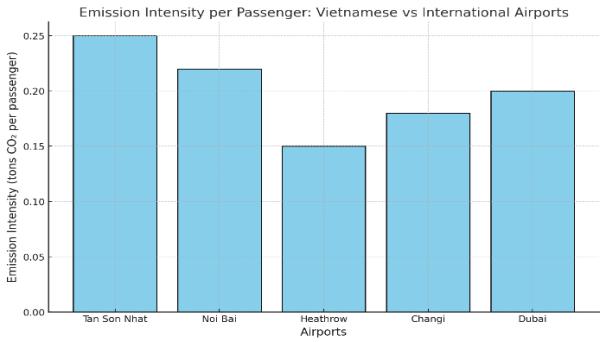

Figure 3. Emission intensity per passenger: Vietnamese vs international airports
(Benchmarking data from ICAO, 2022 and IATA, 2023)

Figure 3 compares the emission intensity per passenger (in tons of CO_2) at Vietnamese airports (Tan Son Nhat and Noi Bai) with international airports (Heathrow, Changi, and Dubai). Vietnamese airports exhibit higher emission intensities, with Tan Son Nhat at 0.25 tons per passenger and Noi Bai at 0.22 tons per passenger. In comparison, Heathrow (0.15 tons), Changi (0.18 tons), and Dubai (0.20 tons) demonstrate lower intensities attributed to their more efficient operations, advanced energy management systems, and integration of renewable energy technologies.

The elevated emission intensity at Vietnamese airports, especially Tan Son Nhat and Noi Bai, can be attributed to several interrelated factors. Foremost among these is inefficient energy usage, with

Vietnamese airports consuming approximately 12.5 kWh of electricity per passenger—significantly higher than the 8.3 kWh at Singapore's Changi Airport and 7.9 kWh at Heathrow. This 40–55% excess energy use results from a continued dependence on conventional grid electricity, over 65% of which is sourced from coal and gas in Vietnam (IEA, 2023). Compounding this issue, the adoption of energy-efficient systems such as LED lighting, automated HVAC units, and intelligent building management platforms remains below 30%, in stark contrast to over 70% implementation at leading global airports. Another significant contributor is the reliance on fossil fuels for ground operations, with over 85% of ground support equipment (GSE) in Vietnamese airports still powered by diesel or gasoline. This contrasts sharply with airports like Schiphol and Vancouver, where electrification of GSE exceeds 50%, resulting in 20–25% lower direct CO_2 emissions per ground movement. Additionally, infrastructure limitations play a role, as most terminals and support facilities in Vietnam's airports lack renewable energy integration. Less than 5% of the surface area at Tan Son Nhat or Noi Bai is covered with solar panels, while airports like Cochin International run entirely on solar power. Inefficient airport layouts also increase fuel consumption and electricity use due to suboptimal aircraft taxiing and passenger flow, causing an estimated 15–20% additional energy waste. Finally, limited technological integration further hinders emission control efforts. Smart grids, IoT-based energy monitoring, and AI-driven predictive maintenance systems are scarcely applied at Vietnamese airports, unlike at technologically advanced hubs such as Changi and Dubai. To mitigate these challenges, Vietnam must prioritize energy efficiency upgrades, expand renewable energy adoption, transition to electric GSE, and embrace digital transformation. By benchmarking against global leaders and implementing these measures, the country's aviation sector could reduce per-passenger emission intensity by 30–40% over the next decade, contributing meaningfully to global net-zero targets and ensuring long-term environmental sustainability.

Building on the analysis of current emission intensities and their underlying causes, it becomes essential to project how these emissions might evolve in the coming years under different policy and operational scenarios.

Predictive Emissions Analysis: Forecasting Emissions Scenarios (2023–2035)

Using linear regression modeling based on emissions data from 2013 to 2022, two projections were developed for Vietnam's major airports. Under the Business-as-Usual (BAU) scenario, if current operational patterns persist without intervention, emissions are projected to reach 58 million metric tons by 2035. In contrast, the Mitigation Scenario, which assumes the implementation of proposed strategies—such as infrastructure electrification, energy efficiency upgrades, and renewable energy adoption—projects a significantly lower emission level of 33 million metric tons by 2035. These forecasts are based on an assumed 6% annual growth rate in passenger traffic, and the model demonstrates a strong fit with historical data, with $R^2 = 0.89$, confirming the reliability of the projections.

3.2. Proposed mitigation strategies

To mitigate GHG emissions from Vietnamese airports, a comprehensive strategy focusing on energy efficiency, renewable energy adoption, electrification of ground support equipment, and innovative waste management is essential.

- Enhancing energy efficiency

Upgrading airport infrastructure can lead to significant energy savings. For instance, O'Hare International Airport in Chicago implemented a Central Utility Plant Upgrade Project, resulting in improved efficiency and reduced energy consumption (Burns & McDonnell, n.d.). Similarly, Birmingham Airport's air handling unit upgrade achieved a 58% energy reduction (Munters, n.d.). Implementing smart energy management systems and energy-efficient technologies can further enhance operational efficiency.

- Transitioning to renewable energy sources:

Adopting renewable energy sources is crucial for sustainable airport operations. Cochin International Airport in India became the world's first fully solar-powered airport, demonstrating the feasibility of large-scale solar integration (Cochin International Airport Limited, 2015). Additionally, Zurich Airport installed a photovoltaic plant on its passenger pier, providing approximately 260 MWh annually (ICAO, n.d.). These examples illustrate the potential for Vietnamese airports to harness solar energy effectively.

- Adoption of electric and low-emission ground support equipment

Electrifying ground support equipment (GSE) can substantially reduce direct emissions. Vancouver International Airport set a goal for 50% of its GSE to operate on electric power by 2020, achieving this target ahead of schedule with 53% electrification by late 2019 (Vancouver Airport Authority, 2020). Implementing similar initiatives can lead to cleaner airport operations in Vietnam.

- Implementation of innovative waste management systems

Effective waste management is vital for minimizing environmental impact. Airports can adopt circular economy principles, ensuring waste materials are repurposed wherever possible. For example, Munich Airport has implemented a biofuel gas station supplying rapeseed oil fuels, ethanol fuel,

and biomethane, facilitating the conversion of vehicle fleets to biofuels (Flughafen München GmbH, 2019). Such initiatives can significantly reduce waste and promote sustainability.

By integrating these strategies, Vietnamese airports can align with global sustainability practices, reduce their environmental impact, and demonstrate leadership in sustainable aviation within Southeast Asia. These efforts not only meet international obligations like the Paris Agreement but also enhance the long-term resilience of airport operations.

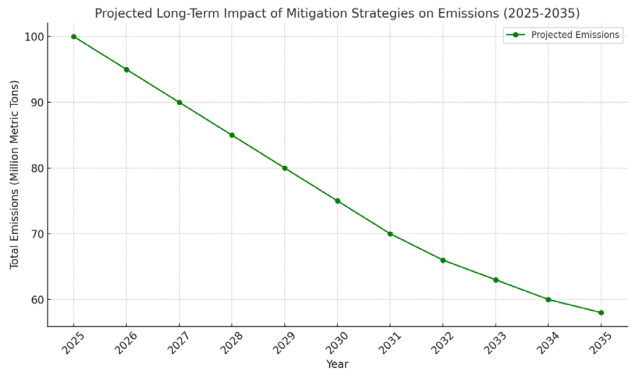

Figure 4. Projected Long-Term Impact of Mitigation Strategies on Emissions (2025–2035)
(Projections based on ACV data and ICAO modeling framework, 2025)

Figure 4 illustrates the projected long-term impact of implementing these mitigation strategies at major Vietnamese airports. Emissions are expected to decrease from 100 million metric tons in 2025 to 58 million metric tons by 2035, aligning with Vietnam's Net-Zero 2050 goals. This projection underscores the importance of adopting renewable energy and operational efficiencies to achieve sustainable growth.

3.3. Case Studies

Adopting successful international practices can significantly enhance the sustainability of Vietnamese airports. Six notable case studies highlight innovative approaches that have successfully addressed environmental challenges at airports worldwide:

3.3.1. Cochin International Airport's solar energy initiative

Cochin International Airport in India became the world's first fully solar-powered airport in 2015. The airport installed a 12 MW solar power plant, comprising over 46,000 solar panels across 45 acres near the cargo complex. This installation generates approximately 50,000 units of electricity daily, meeting the airport's entire energy needs and even contributing surplus power to the state grid. The project's success has led to further expansions, with the airport's total installed solar capacity reaching 50 MWp (Cochin International Airport Limited, 2015).

3.3.2. Schiphol Airport's electrification of ground support equipment

Amsterdam's Schiphol Airport has been actively replacing diesel-powered GSE with electric alternatives to reduce emissions and improve air quality. The airport has introduced electric Ground Power Units (e-GPUs) that supply power to aircraft during ground operations, eliminating the need for onboard auxiliary power units or diesel generators. Additionally, Schiphol is testing innovative energy storage solutions, such as iron flow batteries, to support the increased electrification of its ground operations. These efforts align with Schiphol's ambition to achieve emission-free ground handling by 2030 (Schiphol, 2023).

3.3.3. Townsville and Gold Coast Airports' transition to 100% renewable energy

In Australia, Townsville and Gold Coast airports have committed to sourcing 100% of their electricity from renewable energy starting January 1, 2025. This initiative involves collaboration with CS Energy, utilizing regional renewable projects to supply the necessary 30 GWh of electricity annually. This transition aligns with their master plans for expansion and demonstrates a commitment to sustainable operations (The Courier-Mail, 2024).

3.3.4. Louisville Muhammad Ali International Airport's geothermal HVAC system

In October 2023, Louisville Muhammad Ali International Airport in the United States implemented a geothermal heating, ventilation, and air conditioning (HVAC) system—the largest of its kind in the country. This system utilizes over 600 wells, each 500 feet deep, to leverage the Earth's consistent temperature for efficient heating and cooling. The initiative is expected to reduce the airport's carbon emissions from heating and cooling by more than 80% and save approximately $400,000 annually (Condé Nast Traveler, 2023).

3.3.5. California's sustainable aviation fuel (SAF) partnership

California has partnered with Airlines for America to increase the availability of sustainable aviation fuel (SAF) to 200 million gallons by 2035, aiming to meet about 40% of intrastate travel demand. This initiative is part of broader efforts to combat climate change and improve air quality, positioning the state as a leader in the adoption of cleaner aviation fuels (Austin, 2024).

3.3.6. Sydney Airport's plan for sustainable aviation fuel production

Sydney Airport in Australia is exploring the conversion of a former oil refinery to produce SAF from canola oil and other domestic agricultural products. This project aims to establish Sydney as a central hub in the emerging SAF industry, supporting both environmental sustainability and economic growth. The initiative highlights the potential for airports to play a pivotal role in the production and adoption of sustainable fuels (Sproul-Mellis, 2024).

By studying and adapting these international practices, Vietnamese airports can develop tailored strategies to reduce their environmental impact, enhance operational efficiency, and contribute to global sustainability efforts.

Implications for Vietnamese Airports:

The six case studies highlight practical and scalable solutions for Vietnamese airports to enhance sustainability and reduce GHG emissions. Adapting these practices can enable Vietnam to align its aviation industry with global environmental standards while addressing local challenges.

Cochin International Airport's solar energy initiative demonstrates the feasibility of transitioning to renewable energy by utilizing available land and infrastructure. Vietnamese airports can replicate this approach by installing solar panels on rooftops and vacant areas, reducing reliance on non-renewable energy sources. Similarly, the 100% renewable energy transition by Townsville and Gold Coast airports showcases the benefits of partnerships with energy providers to achieve large-scale decarbonization.

The electrification of GSE at Schiphol Airport emphasizes the importance of investing in electric alternatives to reduce direct emissions. Vietnamese airports could implement similar initiatives, complemented by charging infrastructure and government incentives. Furthermore, the geothermal HVAC system at Louisville Muhammad Ali International Airport provides a model for innovative infrastructure upgrades that cut emissions and operational costs.

Incorporating Sustainable Aviation Fuel (SAF) production and partnerships, as seen in California and Sydney, could help Vietnam position itself as a leader in the SAF market in Southeast Asia, aligning with global trends and fostering economic growth. Together, these strategies offer Vietnamese airports a comprehensive roadmap to sustainability.

The table summarizes six international case studies showcasing innovative sustainability strategies implemented at major airports. These include Cochin's solar power integration, Schiphol's electrification of ground support equipment, and Birmingham's energy efficiency upgrades, which have achieved significant reductions in emissions and operational costs. Additionally, Townsville and Gold Coast airports' transition to 100% renewable energy, Louisville's geothermal HVAC system, and Sydney's plan for sustainable aviation fuel production highlight the potential for renewable energy adoption and advanced technologies. Each case study provides actionable insights and scalable solutions that can be tailored to Vietnam's context, offering a roadmap for enhancing the sustainability of its aviation sector while addressing local challenges.

Challenges and Barriers:

Implementing sustainable practices in Vietnamese airports faces several significant challenges, including financial constraints, shortages of technical expertise,

Table 3. Summarized comparison of international airport sustainability case studies

Airport	Key strategy	Outcome	Challenges	Applicability to Vietnam
Cochin (India)	Solar Power Integration	Achieved 25% emission reduction; first fully solar-powered airport.	Initial infrastructure costs and land requirements for solar panels.	High potential given solar availability; requires financial backing.
Schiphol (Netherlands)	Electrification of Ground Support Equipment	15% emission reduction; implemented electric GPUs and charging stations.	High investment in equipment, electrification, and infrastructure.	Scalable for larger airports; needs policy support and incentives.
Birmingham (UK)	Energy Efficiency Upgrades	20% energy savings; reduced operational costs significantly.	Retrofitting older systems to meet efficiency goals.	Feasible for upgrading the current infrastructure at major airports.
Townsville & Gold Coast (Australia)	100% Renewable Energy Transition	Committed to sourcing all electricity from renewable energy by 2025, leveraging local projects.	Partnering with energy providers to ensure a consistent supply.	Feasible with collaboration between airports and renewable energy providers.
Louisville (USA)	Geothermal HVAC System	Reduced emissions by 80% from heating and cooling; $400,000 annual cost savings.	High initial cost for drilling geothermal wells.	Potential for larger airports with significant heating/cooling needs.
Sydney (Australia)	Sustainable Aviation Fuel (SAF) Production	Planning to produce SAF from agricultural products; supports regional economic growth.	Conversion of existing facilities and scaling SAF production.	High potential to position Vietnam as a leader in SAF production in Southeast Asia.

and regulatory hurdles.

- Financial Constraints

Developing airport infrastructure in Vietnam requires substantial investment. The Vietnamese government plans to spend approximately USD 17.8 billion on nationwide aviation development from 2021 to 2030, and USD 25.48 billion up to 2050. However, attracting private investment is challenging due to concerns about financial viability, especially for smaller airports. Regulatory complexities and the need for clear investment policies further complicate funding efforts (PwC, 2024).

- Shortages of technical expertise

The rapid growth of Vietnam's aviation sector has led to a demand for skilled professionals, including pilots, engineers, and air traffic controllers. However, there is a notable skills gap, particularly in digital literacy and technical expertise among small and medium-sized enterprises (SMEs). This shortage hampers the adoption of advanced technologies and sustainable practices essential for modern airport operations (Nguyen, 2024).

- Regulatory Hurdles

Navigating Vietnam's regulatory environment poses challenges for both domestic and foreign investors. Complex approval processes, lack of transparency, and inconsistent enforcement of regulations create uncertainties that can deter investment in airport infrastructure. Efforts to streamline government decision-making and minimize administrative hurdles are essential to make Vietnam a more attractive market for private sector airport development. (Eurogroup Consulting, n.d.).

Addressing these challenges requires coordinated efforts between government agencies, private stakeholders, and international partners to secure funding, build capacity, and develop supportive regulatory frameworks. By overcoming these barriers, Vietnamese airports can enhance their sustainability and operational efficiency, aligning with global standards and contributing to the country's economic growth.

4. Conclusion

4.1. Summary of Findings

This study highlights the potential of adopting sustainable strategies in Vietnamese airports to address environmental challenges while achieving economic and social benefits. The proposed strategies—enhancing energy efficiency, transitioning to renewable energy, electrifying GSE, and implementing innovative waste management systems—offer a comprehensive approach to reducing GHG emissions. These measures not only decrease the environmental footprint of airports but also contribute to long-term cost savings by reducing energy consumption and improving operational efficiency. Socially, these initiatives can enhance air quality, create green jobs, and bolster Vietnam's reputation as a leader in sustainable aviation.

The findings underscore the alignment of these strategies with Vietnam's climate goals and international commitments, such as the Paris Agreement. By reducing reliance on fossil fuels and adopting renewable energy, Vietnamese airports can support the national objective of achieving net-zero emissions by 2050. Furthermore, implementing these measures positions Vietnam to meet global aviation sustainability standards and maintain competitiveness in the international market.

Ultimately, integrating these practices into Vietnam's aviation sector represents a significant step toward environmental stewardship, economic development, and social progress. With coordinated efforts from government agencies, private stakeholders, and international partners, Vietnam can transform its airports into models of sustainability in Southeast Asia.

4.2. Recommendations

To guide Vietnam's aviation sector toward its net-zero target by 2050, a set of strategic policies is recommended. First, a national emissions reduction target should be established, mandating a 40% cut in airport-related emissions by 2040, with clearly defined benchmarks set at five-year intervals to ensure progress. In support of cleaner fuels, a Sustainable Aviation Fuel (SAF) policy is proposed, beginning with a 2% blending mandate by 2027 and increasing to 10% by 2035, alongside tax incentives to encourage domestic SAF production. Additionally, a Green Airport Certification Program modeled after the Airport Carbon Accreditation system should be introduced, requiring all international airports in Vietnam to meet certification standards by 2030. To further incentivize emissions reduction, a carbon pricing pilot is recommended for major hubs such as Tan Son Nhat and Noi Bai by 2028, with collected fees reinvested into low-carbon infrastructure projects. Finally, robust monitoring and accountability mechanisms must be put in place through the creation of an independent Aviation Sustainability Council, which will be tasked with publishing annual GHG performance dashboards and conducting third-party audits. Collectively, these measures reflect Vietnam's commitment to the Paris Agreement and ICAO environmental goals, positioning the nation as a regional leader in sustainable aviation development.

To achieve sustainable development in Vietnamese airports, a set of actionable recommendations is proposed, focusing on fostering partnerships, building technical capacity, and improving regulatory processes. These measures will enable Vietnam to overcome

existing challenges and align its aviation sector with global sustainability standards.

(1) Foster public-private partnerships and provide financial incentives

Collaboration between the public and private sectors is essential to driving sustainable initiatives in Vietnam's aviation sector. Public-private partnerships (PPPs) serve as a powerful mechanism to attract private investment and technical expertise while ensuring government oversight. To actualize these benefits, the government must take a structured approach, beginning with:

Stage 1: Policy framework development (3–6 months)

Ministry of Transport (MOT) and Ministry of Finance (MOF): Establish a clear policy framework outlining the scope, benefits, and legal structure of PPPs for sustainable airport projects. This includes identifying priority areas such as renewable energy, electric GSE, and waste management. Policies should also define financial incentives, including tax breaks, subsidies, and low-interest loans.

Stage 2: Stakeholder engagement and investment roadshows (6–12 months)

MOT, Civil Aviation Authority of Vietnam (CAAV), and key airport operators: Organize stakeholder meetings and investment roadshows to attract private investors and technical partners. Highlight successful international PPP models, such as Cochin International Airport's solar energy initiative, to showcase benefits and feasibility. Collaboration with international organizations like the World Bank or Asian Development Bank can further strengthen the PPP framework.

Stage 3: Project implementation and monitoring (12–36 months)

Private sector investors, airport authorities, and CAAV: Select pilot projects at major airports (e.g., Tan Son Nhat or Noi Bai) to implement renewable energy installations, electric GSE adoption, or waste management systems. Establish monitoring mechanisms to evaluate performance and address challenges. Provide periodic reports to ensure transparency and accountability.

By adhering to this timeline and allocating responsibilities effectively, Vietnam can successfully mobilize PPPs to advance sustainable practices in its aviation sector.

(2) Build technical capacity and streamline regulatory processes

To effectively address technical expertise shortages and regulatory inefficiencies, Vietnam must adopt a phased approach that complements its efforts to foster public-private partnerships (PPPs). While capacity-building programs equip airport staff with essential skills in renewable energy, electric vehicle maintenance, and waste management, streamlined regulatory processes ensure the timely implementation of these initiatives. These efforts align with the development of a clear policy framework under:

Stage 1: Assessment and Planning (3–6 months)

Ministry of Transport (MOT) and Civil Aviation Authority of Vietnam (CAAV): Conduct a comprehensive skills gap analysis to identify areas requiring capacity building, focusing on renewable energy systems, electric vehicle (EV) maintenance, and waste management. Simultaneously, review existing regulatory frameworks to identify bottlenecks and inconsistencies that hinder the implementation of sustainable practices. Collaborate with international organizations such as ICAO and ACI for expert guidance.

Stage 2: Capacity-building initiatives (6–12 months)

MOT, CAAV, and partnered international organizations (e.g., World Bank, IATA): Develop and implement training workshops, certification courses, and hands-on programs for airport staff and key stakeholders. Leverage expertise from global organizations to provide technical training in specialized areas. Additionally, design manuals and guidelines to support ongoing learning and application of sustainability-focused technologies.

Stage 3: Regulatory streamlining and pilot programs (12–18 months)

MOT, CAAV, and Ministry of Justice: Reform regulatory frameworks to align with international standards, ensuring clarity and reducing approval delays. Establish pilot programs to test simplified processes and assess their effectiveness. Use feedback from these programs to refine regulations and create a transparent, investor-friendly environment.

By systematically addressing technical skill gaps and regulatory inefficiencies, Vietnam can accelerate the adoption of sustainable practices in aviation, ensuring that the sector aligns with global best practices and remains competitive in the Southeast Asian market.

(3) Encourage stakeholder collaboration through knowledge-sharing platforms

Establishing knowledge-sharing platforms is essential for fostering collaboration and driving innovation in Vietnam's aviation sector. By creating forums, conferences, and digital tools, stakeholders can exchange best practices, address challenges, and develop strategies tailored to the unique needs of Vietnamese airports. This process begins with:

Stage 1: Needs assessment and platform design (3–6 months)

Ministry of Transport (MOT), Civil Aviation Authority of Vietnam (CAAV), and academic institutions: Conduct a needs assessment to identify key topics and stakeholders for knowledge-sharing initiatives. Design the framework for the platforms, including both physical events (forums and conferences) and digital tools (online portals and

webinars). Collaborate with academic institutions and international organizations like ICAO or IATA to ensure content relevance and global best practices integration.

Stage 2: Launch and Implementation (6–12 months)

MOT, CAAV, and private sector partners: Organize the first series of forums and conferences to bring together policymakers, airport operators, private investors, and academics. Topics should include renewable energy, sustainable airport operations, and regulatory reforms. Simultaneously, launch an online platform to facilitate ongoing discussions, share reports, and archive best practices. Encourage stakeholder participation by offering incentives, such as certificates for contributions or discounted event fees for early adopters.

Stage 3: Monitoring and Expansion (12–24 months)

MOT, CAAV, and academic institutions: Evaluate the effectiveness of initial events and digital platforms through feedback surveys and participation metrics. Use insights to refine and expand the platforms to include regional and international stakeholders. Establish annual forums and integrate virtual reality (VR) or augmented reality (AR) tools for more interactive knowledge sharing.

By developing these platforms, Vietnam can foster collaboration, accelerate innovation, and create tailored solutions for its aviation sector's sustainability challenges.

REFERENCES

Airports Council International (2021). *Sustainability practices for airports*. Montreal, Canada: Airports Council International.

Airports Council International (2022). *Environmental best practices for sustainable airports*. Montreal, Canada: Airports Council International.

Austin, S. (2024). *California announces sustainable fuels partnership to curb emissions from planes*. Associated Press.

Burns & McDonnell (n.d.). *Central utility plant upgrade project case study*.

Changi Airport Group (2022). *Sustainability report 2021/22*.

Condé Nast Traveler (2023, October). *Bright ideas in travel 2024*. Accessed at https://www.cntraveler.com/story/bright-ideas-in-travel-2024. Accessed on January 1, 2025.

Cochin International Airport Limited (2015). *Cochin International Airport becomes the first fully solar powered airport in the world*.

Dubai Airports (n.d.). *Social responsibility*. Accessed at https://dubaiairports.ae/corporate/our-story/Social-Responsibility.

Eurogroup Consulting (n.d.). *Navigating regulatory challenges for foreign businesses in Vietnam: A strategic approach*. Accessed at https://marketresearchvietnam.com/navigating-regulatory-challenges-for-foreign-businesses-in-vietnam-a-strategic-approach/. Accessed on January 1, 2025.

Flughafen München GmbH (2019). *Sustainability and Environmental Report*.

Heathrow Airport Limited (2022). *Sustainability report 2021*. Accessed at https://www.heathrow.com/content/dam/heathrow/web/common/documents/company/heathrow-2-0-sustainability/futher-reading/2021_Sustainability_Report.pdf

Nguyen, H. P. (2024). Evolving management practices in Vietnam: Navigating globalization, digital transformation, and sustainability. *International Journal of Economics, Business and Management Research,* 8(11).

International Civil Aviation Organization (ICAO) (2022). *Carbon emission mitigation frameworks*. Montreal, Canada: ICAO.

International Civil Aviation Organization (ICAO) (n.d.). *Sustainability practices for airports*. Montreal, Canada: ICAO. Accessed at https://www.icao.int/environmental-protection/Pages/Airports.aspx.

International Civil Aviation Organization. (n.d.). *Zurich Airport Photovoltaic Plant*.

International Energy Agency (2023). *Vietnam electricity market report*. Paris, France: IEA Publications.

Munters (n.d.). *Air handling unit upgrade saves 58% energy*. Accessed at https://www.munters.com/en-ie/knowledge-bank/case-studies/casestudy-6073/. Accessed on January 1, 2025.

PwC (2024). *Viet Nam airport sector: Development and investment opportunities*. Accessed at https://www.pwc.com/vn/en/publications/2024/vietnam-airport-sector.pdf. Accessed on January 1, 2025.

Schiphol (2023). *New electric equipment for parked planes at Schiphol*. Accessed at https://nieuws.schiphol.nl/en/new-electric-equipment-for-parked-planes-at-schiphol/. Accessed on January 1, 2025.

Sproul-Mellis, E. (2024). *Sydney Airport eyes former Kurnell oil refinery for canola conversion to sustainable aviation fuel*.

The Courier-Mail (2024). *Townsville, Gold Coast airports to switch to 100% renewable power*.

United Nations Framework Convention on Climate Change (UNFCCC) (2021). *Net-zero 2050 targets: A guide to sustainable action*. Bonn, Germany: UNFCCC Secretariat.

Vancouver Airport Authority (2020). *Environmental Management and Climate Action Report*.

Vietnam Airlines (2021). *Annual report 2021*. Ho Chi Minh City, Vietnam: Vietnam Airlines.

Vietnam Civil Aviation Authority (2022). *Statistical review*. Hanoi, Vietnam: Vietnam Civil Aviation Authority.

World Bank (2020). *Vietnam Economic Development Report.* Washington, DC: World Bank Group.